BBC RD 1977/26

1974
THE QUEEN'S AWARD
TO INDUSTRY

RESEARCH DEPARTMENT REPORT

CEEFAX: evolution and potential

J.R. Chew, B.Sc. (Eng.), M.I.E.E.

Research Department, Engineering Division
THE BRITISH BROADCASTING CORPORATION August 1977

BBC RD 1977/26
UDC 621.397

CEEFAX: EVOLUTION AND POTENTIAL

J.R. Chew, B.Sc. (Eng.), M.I.E.E.

Summary

The development of the CEEFAX information broadcasting system from initial work in 1966 to the end of the two-year experimental period in 1976 is described.

The background to the choice of transmission and display parameters is given, together with details of laboratory and field experiments. Particular emphasis is given to the selection of the addressing and coding systems to give reliable reception throughout the normal television service area.

The basis for the choice of the many supplementary facilities of CEEFAX, such as colour and graphics, is presented together with indication of the provisions made for future expansion in the use of CEEFAX

Issued under the authority of

G.D. Monteath

Head of Research Department

Research Department, Engineering Division,
BRITISH BROADCASTING CORPORATION
August 1977

(PH-155)

CEEFAX: EVOLUTION AND POTENTIAL

CEEFAX: EVOLUTION AND POTENTIAL

J.R. Chew, B.Sc.(Eng.), M.I.E.E.

1. Introduction

The first BBC experimental transmissions to explore the possibilities of a new broadcast information service called CEEFAX began on 12th March, 1973. A specification for these experimental transmissions was published in April, 1973 and widely circulated to enable those interested to design and build CEEFAX receiving equipment.

The aim of the CEEFAX proposal was to use a suitably equipped domestic television receiver, and the existing television channel which feeds it, to provide an extra service of written news and other information to the viewer. Fig. 1 shows the basic arrangement of equipment to do this. The viewer is able, by using the page selector, to call up at will any one of a number of pages of data and to display it on his television screen. Fig. 2 shows two examples of such pages. The set of pages available for selection at any time is called the 'MAGAZINE'.

Although many details of the CEEFAX system are discussed in this report, the authoritative definition is given elsewhere.[1]

1.1. Origins of the CEEFAX proposal

During 1966 to 1968 BBC Designs Department designed and tested prototype equipment for transmissions of data using lines in the television field-blanking interval. The information transmitted was intended to assist in the control of the television network, and the apparatus was known as "Vertical Interval Communication Equipment".

On 11th December, 1970 the then head of Designs Department,* prepared a note on 'Electronic Methods of domestic data displays'. During the following year Research Department explored the field-interval transmission method and an alternative proposal to use a television-sound subcarrier for the same purposes.

In November 1971 a meeting took place between members of Designs and Research Departments to discuss domestic data broadcasting and the proposal to do so using lines in the field-blanking interval, at that time known as TELEDATA.

* Mr. Peter Rainger

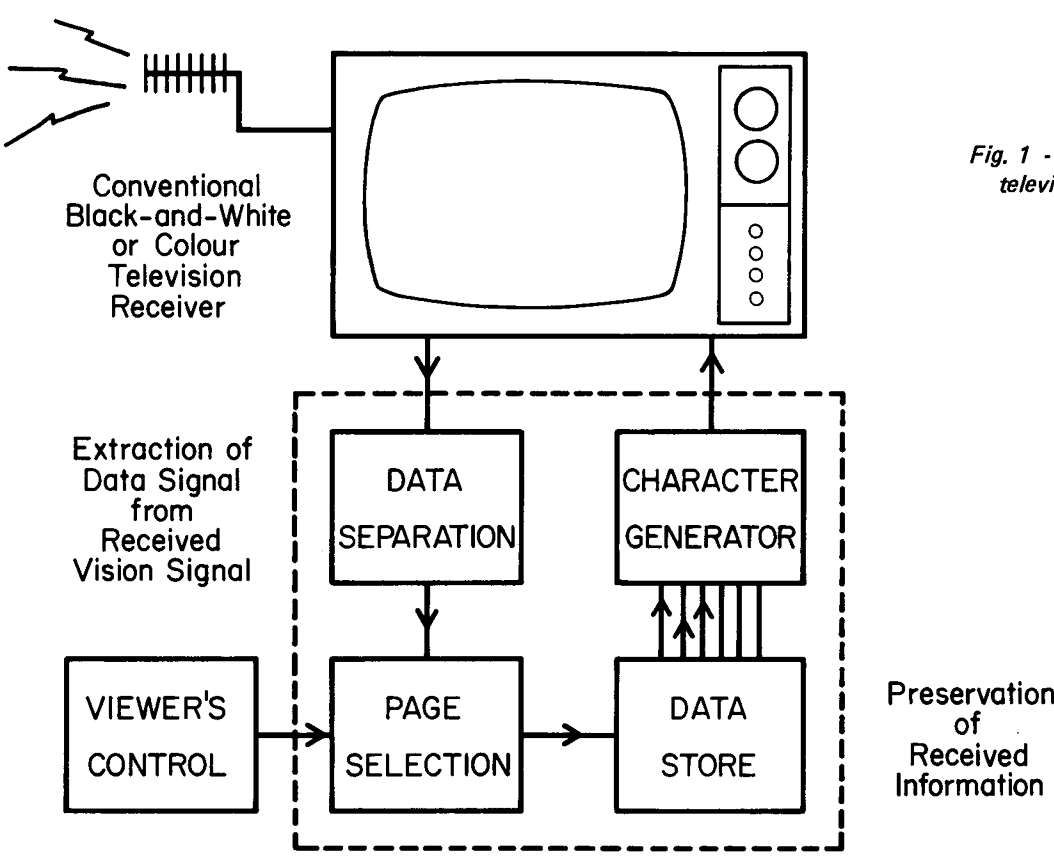
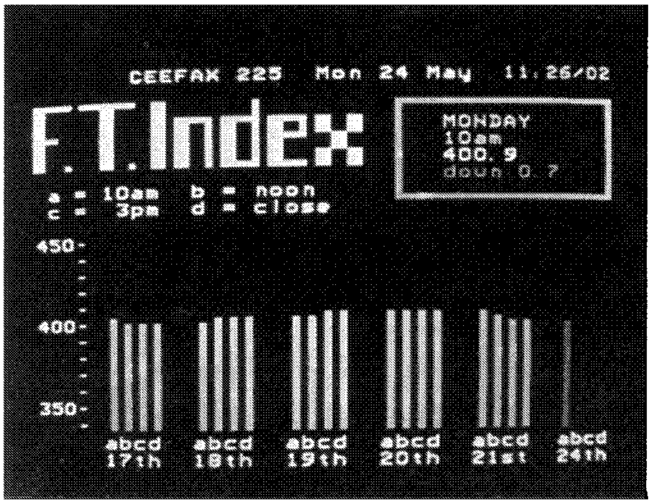


Fig. 1 - Additions to domestic television receiver to receive CEEFAX



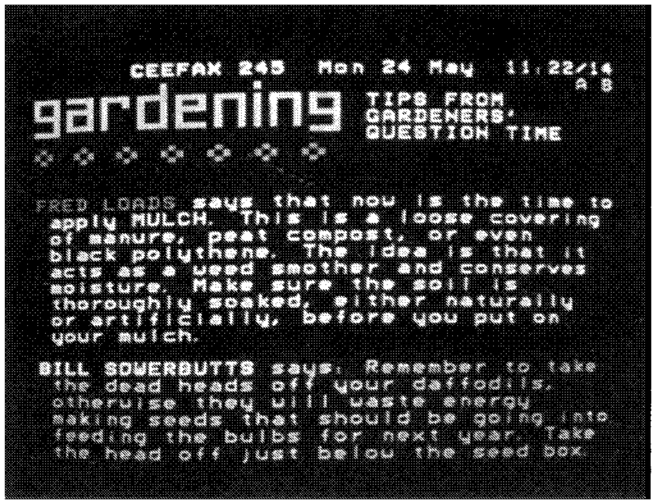


Fig. 2 - Two examples of received CEEFAX pages

A provisional patent application was filed on 9th February, 1972 entitled 'Transmission of alphanumeric data by television'. A complete patent specification No. 1370935 was subsequently published.

A brochure outlining the facilities which such a service was anticipated to be capable of providing, was published in May 1972, and work to study the proposals further and to build prototype equipment, started in July and August respectively.

The TELEDATA proposal was renamed CEEFAX on 11th September, 1972.

2. Main requirements of a domestic data-broadcasting service

2.1. User satisfaction

(a) The capacity of the service should be large enough to allow the broadcaster to provide a comprehensive range of information.

(b) The information should be provided promptly so as not to try the patience of the user.

(c) The eventual cost of the receiving equipment should be reasonable.

(d) The display facilities should be such as to encourage the service editors to produce attractively varied presentation of data on different pages.

2.2. Compatibility

(a) The transmission of data should be accomplished without interfering with normal television viewing.

(b) The data signal should not place new and onerous requirements on the maintenance of the broadcaster's distribution network.

(c) The service area of the data transmission should not be less than that of the associated colour television signal.

2.3. General

(a) The effects of transmission errors should be minimized.

(b) The transmission should be arranged so as to offer as many options as possible in the design of the receiving equipment.

(c) The form of the transmissions should facilitate future expansion of the service and not prejudice the future development of new uses.

3. Transmission

3.1. Choice of basic transmission method

The signals carried by a television broadcast channel are such that there is a number of possible ways in which a data signal may be added. Although the most obvious of these involve the intervals when television line-blanking or field-blanking occur, various other possibilities have also been considered, including a subcarrier added to the television-sound signal, or an additional carrier located within the television broadcast band. These other methods were finally rejected because of the complexities or expense which they involved. It was decided that transmitting the data during the television field-blanking interval was the optimum method.

The duration of each field-blanking interval is 25 lines of which the first 7½ lines are used to transmit the field-synchronising signal and the associated equalizing pulses. The receiver field-flyback continues during the

following lines and is completed before the resumption of picture transmission on lines 23 or 336. Lines 13(326) and 14(327) were originally proposed for data transmission, and broadcast tests were carried out[2] to discover whether data pulses transmitted during these lines would cause interference to normal television viewing. It was found that about 7% of television receivers, which had long flyback-times coupled with poor flyback suppression, displayed the data pulses as sloping lines of bright dots in the active picture area. Transfer of the data to television lines 17(330) and 18(331) removed the difficulty, since all the receivers tested (about 200) had then either completed field-flyback before the arrival of the data, or had adequate flyback suppression. Lines 17(330) and 18(331) were therefore adopted for the initial CEEFAX transmissions.

3.2. Primary coding

To display English text in a fully satisfactory readable form, both upper and lower case letters are required, together with numbers and punctuation marks. A number of arithmetic signs, arrows, brackets and the like are similarly indispensable in the display of numerical information.

These requirements can be met by a set of not more than 96 different characters. Each of 96 characters can be allocated a seven-bit binary code, with 32 codes remaining for control purposes. Such codes are already in common use and the subject of international standardization.

3.3. Transmission coding

The character coding, sometimes referred to as the primary coding, describes the required information with great efficiency. There is, however, a further consideration as to whether the primary code is entirely suited to the transmission method, or whether benefit may be obtained from a further coding process, known as secondary coding, to suit the data better to the transmission medium. A secondary coding process would give a transmission code different from the primary code.

One of the major requirements for a transmission code for CEEFAX is to enable as high a bit-rate as possible to be used in the allotted band-width, so as to provide rapid access to any page of a magazine of useful size. The suitability of transmission codes was investigated,[3] attention being concentrated on NRZ (Non Return to Zero) binary, Biphase, and Delay Modulation codes.[4] Multilevel codes such as ternary, quaternary etc., which yield still higher bit rates in a given bandwidth, were rejected on the grounds of receiver complexity and sensitivity to noise in poor reception conditions.

Within a given bandwidth it was found that NRZ can be transmitted at at least twice the bit rate of Biphase for the same error resistance to noise.

NRZ also withstands bandwidth limiting more readily than Delay Modulation because of the effect of intersymbol interference on Delay Modulation.

Two factors which frequently militate against the adoption of NRZ binary coding for data transmission are, first, that the data signal has a large low-frequency component and secondly that occasionally there is no timing information contained in an unconstrained NRZ binary signal. Neither disadvantage was significant in the CEEFAX application because the d.c. component of the data signal is small compared with that of the picture signal itself, and parity checking of the data, desirable for the reasons given below in Section 3.7., can easily be arranged to ensure that there is always sufficient timing information to synchronize the receiver. The coding chosen for transmission was therefore NRZ binary, both for the experimental CEEFAX system and later for Teletext.

The CEEFAX transmission is therefore not subject to a secondary coding operation, and an initial decoding operation to recover the primary code is not required in domestic receivers.

3.4. Bit rate

In a study carried out in 1970-71, it had been concluded that one television line could carry no more than 130 bits of data; this would be achieved using Biphase code giving a data rate of 2·5 Mb/s with a clock rate of 5 MHz. These hitherto unpublished conclusions had been arrived at on the basis that the performance and tuning of data receivers would be no better than that of monochrome television receivers in widespread use at that time.

The adoption of such a transmission rate for CEEFAX would have led either to so small a magazine, or such a long access time, as to severely reduce its attraction to the would-be user. Since the CEEFAX proposal was concerned with specifying a service for the future it was necessary, at its inception, to adopt standards which would fully exploit the available technology. Not to do so would have resulted in a system that would be quickly rendered obsolete.

Developments in receiver design, such as automatic frequency control and the possible use of surface acoustic wave (SAW) filters, led to the opinion that domestic CEEFAX receivers of the near future would not be worse in performance than the best domestic television receivers of 1971, a view shared by BREMA.*

The initial CEEFAX experiments were accordingly made using a bit-rate of 4·5 Mb/s, the increase being obtained by use of NRZ coding. Successful reception of CEEFAX at this data rate was confirmed by field trials carried out using a mobile laboratory at the edges of the Crystal Palace transmitter service area. A further series of field trials was later carried out (January '74) in which CEEFAX data was transmitted at 4·5, 5·75 and 6·875 Mb/s, and again received in a mobile laboratory in

* British Radio Equipment Manufacturers' Association.

the Crystal Palace service area. The results of these trials[5] showed that the signal strength required for correct reception of CEEFAX was not materially increased by transmission at the highest bit-rate, and that the minimum field strength required was between 6 and 11 dB lower than that necessary for satisfactory colour television reception.

On the basis of this work the BREMA working party set up to co-ordinate the development of Teletext proposed that a bit rate of 6·9375 Mb/s be adopted for Teletext transmission.

3.5. Capacity of transmission block

In principle the quantity of data transmitted on a television line (transmission block) need not bear any simple relationship to the number of characters displayed on one row of the screen. In practice, however, the design of the receiver is simplified, and the receiver therefore cheapened, if a complete row of displayed text together with the necessary address information is transmitted as a block on each television data line.

3.6. Data level

To allow correct reception of data in the presence of noise it is desirable to adopt as high a voltage difference as possible between the binary states. It is nevertheless also necessary that the data swing should not be so large as to cut off the carrier and so produce intercarrier buzz on the television receiver sound channel. Instances of CEEFAX buzz were in fact reported during the experimental period. When these were investigated, they were found to have been caused by misalignment of a particular model of receiver, or very occasionally by misalignment of the transmitter. Receivers exhibiting CEEFAX buzz invariably exhibit severe caption buzz also.[6]

The initial experiments were conducted with a data swing of 0·35 volt i.e. from black level (data 0) to 50% of white level (data 1). Experience showed that the data swing could be increased somewhat without ill effect and the binary 1 level was eventually specified at (66±6)% of peak white, the binary 0 level remaining at black level (0±2)%.

3.7. Errors in displayed data

Errors in the data displayed on the screen, would ordinarily result in a number of wrong characters amongst the text when the errors are random. This effect would be seen at the edge of the CEEFAX service area where the errors are usually caused by noise. In such circumstances single errors per character are much the most probable. By providing each seven-bit transmitted character with a parity check bit these single errors may be readily detected by the decoder and the erroneous characters ignored.

On first acquisition in these poor conditions a CEEFAX page would normally appear impaired by spaces or substitute characters, indicating errors. Subsequent transmissions of the same page would not in general have errors in the same places and consequently these positions would be filled by the correct characters as the page was repeatedly transmitted. Only the less frequent double errors in a character would cause wrong characters to appear.

4. Addressing

Addressing is used:

(a) To identify the transmitted data so that the decoder can select the particular magazine and page required by the viewer.

(b) To number the rows of a page to ensure their correct placement on the screen.

(c) To identify and capture information which is transmitted only briefly according to a time schedule.

4.1. Degree of addressing

It is important in transmitting data like CEEFAX to optimise the degree of addressing to be employed. One extreme is to address every transmitted character, which would waste most of the transmission capacity of the system: another is to transmit addressing information only infrequently and arrange that the receiver counts the television synchronizing pulses so as to derive the intervening addresses. The latter, though highly economical, leads to a relatively fragile system in which a single disturbance can have a considerable and prolonged effect.

For the experimental CEEFAX system, transmitted from July 1973 to April 1974, it was decided to address fully each transmission block by including in it the page number, row number and time addresses; doing so had the advantage of flexibility in that pages and rows could be transmitted in any sequence. (A discussion of transmission sequence is given in Section 7. In the experimental system the address information occupied more than 17% of the complete transmission time.

In the subsequent Teletext system the degree of addressing was reduced, in that page numbers and time addresses were transmitted only once per page of information on a special row known as the 'page header'; all other rows carried only the magazine number and row address. As a result the address information now occupies some 5% of the transmission time.

Although the magazine number which appears as the first digit of the page number might be considered to be more naturally associated with the page than with each separate row its inclusion with the row address fits conveniently into the row address data group and, moreover, will permit the independent interleaving of two or more magazines if required.

Since the page address is to be compared with one

selected by the viewer it is transmitted in binary-coded decimal notation (BCD). The row address, however, which operates automatically upon the decoder is transmitted in the more compact binary code.

4.2. Time address

For purposes to be discussed in Section 11.2. it was necessary to include a time address in both the experimental transmission and in Teletext. At present this address represents, in binary-coded decimal notation, the clock-time at which the page is transmitted in hours and minutes.

4.3. Potential of unused addresses

The addresses of the 24 rows (numbers 0 to 23) and the time-codes which normally occur (minutes 0 to 59, hours 0 to 23) represent less than the full range of codes possible with the transmission bits allocated to them. Apart from 'minutes' codes in the range 60 to 79, and 'hours' codes in the range 24-39, which should be accessible by a decoder, these other codes must be ignored as they may be used for other purposes in the future. These conditions have been built into the Teletext specification.

4.4. Address error protection

Under poor reception conditions errors are likely to occur both in the reception of the transmitted data and the addresses. Address errors are the more serious since they may cause intrusion of matter from other pages into the required page, mis-positioning of complete rows of text on the page, or failure to acquire a complete page of text.

In the experimental CEEFAX system, where each row of text was separately and fully addressed, loss of an address could only affect one row and so attention was concentrated on detecting false addresses. To this end each address was transmitted twice, one copy being inverted, time reversed, and interleaved with the other. Only if both versions of the address were found to agree was the information stored and subsequently displayed.

In the final CEEFAX system, on the other hand, loss of an address in the page header inevitably prevents the acquisition of a whole page of data. Therefore, the chief requirement is to acquire the page header correctly by correcting erroneous addresses wherever possible. For this reason the page and row addresses are protected by incorporating them in a single-error correcting, double-error detecting 'Hamming' code.[7]

Figs. 3(a), (b) and (c) show the calculated probabilities of true, rejectably wrong, and undetectably false, transmission for a message eight bits long incorporated in two eight-bit Hamming code groups.

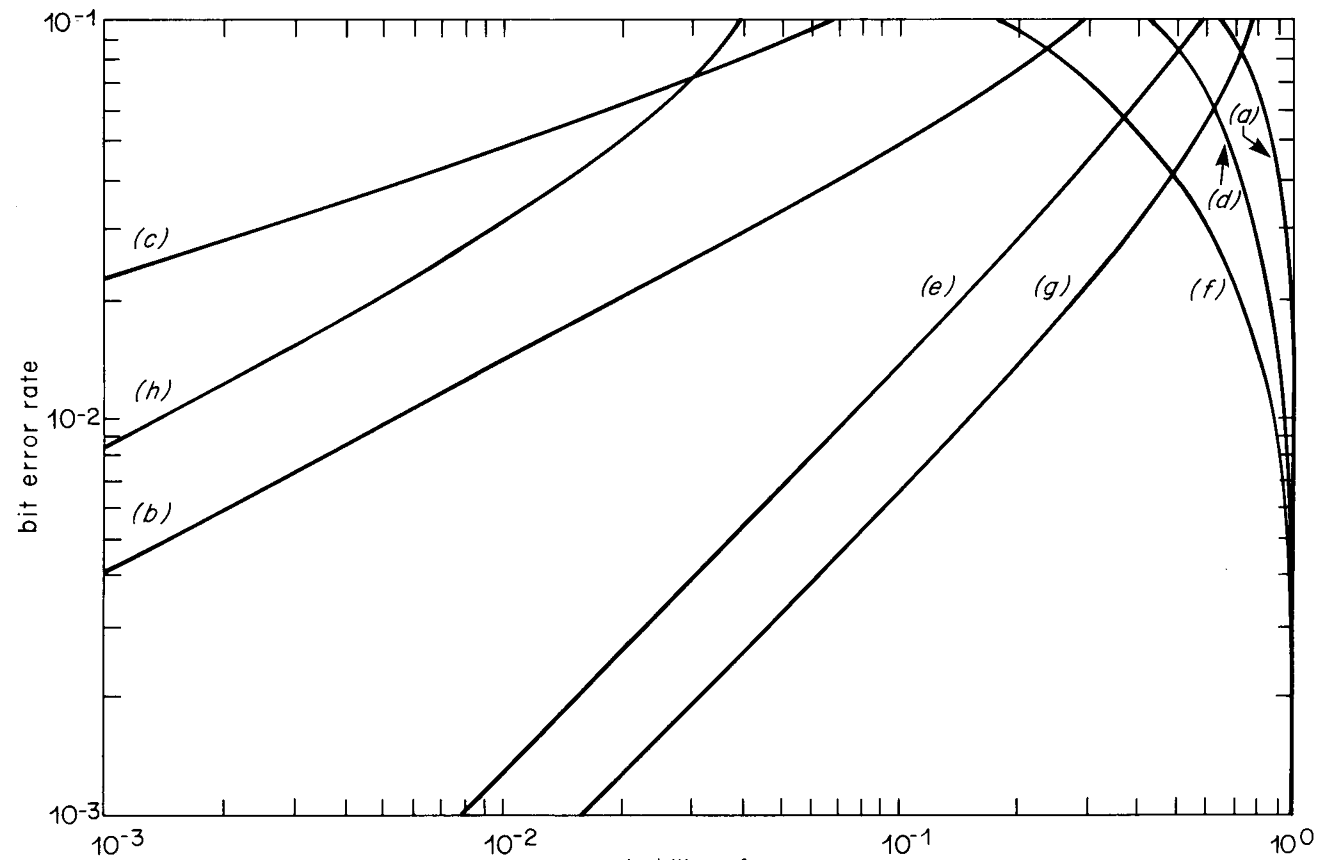


Fig. 3 - Error susceptibility of various methods of address transmission

Figs. 3(d) and (e) show the probabilities of correct and false reception of a single unprotected message of eight bits in the same channel for comparison. Figs. 3(f), (g) and (h) show the probabilities of true, rejectably wrong, and undetectably false reception of an eight-bit message transmitted twice and compared for agreement.

From curves (a), (d) and (f) it will be seen that of the systems compared the Hamming coded form always provides the greatest proportion of correct messages, and from curves (a) and (c), (d) and (e), (f) and (h), that Hamming code also provides the greatest ratio of correct to undetectably false messages. The calculations, which are detailed in the Appendix, assume the random occurrence of errors.

5. Clock starting and synchronizing sequence

Since the CEEFAX data lines occur only during the television field-blanking periods, and the data timing may vary from data line to data line, the decoder must be able to achieve bit and byte synchronism on every individual data line.

To acquire data successfully, therefore, it is necessary to establish a source of clock pulses in phase with the incoming data bits (bit synchronism). Having achieved this, the point where the message begins must be determined (byte synchronism).

To establish correctly phased clock pulses, a group of not less than twelve bits in a repeated 1-0-1-0 sequence is placed at the start of each data line to provide the maximum possible density of timing reference points. To locate the start of the message a framing code having a fixed and recognisable 8 bit pattern then follows. The framing code is used as a test word which is compared with the last eight bits of the incoming signal as the latter is clocked through a shift register.

In the same way that addressing information must continue to work in the presence of an error, the framing code must not be missed when in the correct position nor falsely detected when in the wrong position. If it were, complete rows of data, and possibly a whole page, would be lost.

The design of the framing-code for CEEFAX to operate correctly, even under poor reception conditions where one bit of the eight may frequently be in error, was found to involve factors which were not immediately apparent. To allow for a single bit error within the received framing code it is necessary to accept either seven or eight coincidences with the test word as evidence of correct framing. On the other hand the framing code must prevent false indication of the message start during reception of the clock-run-in sequence. This sequence may be shortened or corrupted by initial lack of synchronism of the bit clock. It may also be corrupted by transmission errors. The framing-code must therefore be very different from the run-in sequence, and from all partial combinations of the run-in sequence and the code itself which follows. Computer analysis was used to assess the performance of all possible 8 bit codes. Workable codes were those which never presented more than 5 coincidences of value leaving room for one bit error without satisfying a seven-out-of-eight comparison. The best codes were taken to be those with the minimum number of quintuple coincidences during the clock run-in period.

All workable codes, because of their necessarily large difference from the 10101010 sequence contain few transitions, the code chosen for CEEFAX, 11100100 contains three. The codes therefore represent very simple pulse waveforms as transmitted. When operating with a 'seven-out-of-eight' detector as appropriate to single error conditions such codes are vulnerable to the clocking through of simple pulse waveforms in the applied signal. The primary function of the framing code is synchronization, it is not the sole identification of a Teletext data line. In particular it is desirable that the framing code detection should only take effect when a framing code can be expected, and even then only if, previous to this time there has appeared a burst of sufficient energy at half clock frequency to confirm the presence of the clock-run-in sequence. The latter condition provides protection against other types of data signals.

6. Magazine size and access time

In the first transmissions of CEEFAX one row of characters occupied the two data lines in each television field-blanking interval. The complete magazine of 32 pages each with 24 rows therefore took 15·36 s to transmit. This represented the longest waiting time before reading of a completed page could be begun. This waiting time was found acceptable to the majority of people to whom the system was demonstrated.

The increased bit rate and addressing economy later achieved for the unified standard published in October 1974, permitted two character rows to be transmitted in each field-blanking interval, one on each of the data lines. The page transmission time was therefore halved and a one hundred page magazine transmitted in full in 24 s.

As discussed in Section 3.1. transmission of CEEFAX on additional lines earlier in the field blanking interval is at present ruled out because some television receivers (7% in 1974) are not provided with adequate flyback-blanking. Any use of lines occurring whilst the flyback is still in progress would therefore mar the television picture on such sets. It is expected that television receivers will be provided with adequate flyback blanking so when the older models are no longer in use it will be possible to use additional data lines earlier in the field blanking interval.

In that case a considerable expansion of the information rate in Teletext will be possible. Ample addressing capability has been provided to allow for future increases in the number of pages.

In the meantime any Teletext service originator may

choose to originate up to 800 pages, but at a penalty of increased access time. The eight one-hundred page magazines are capable of being entirely independent, so that, for example regional and national CEEFAX magazines may be sent simultaneously without interference, a compact news magazine can co-exist with a longer general magazine, or subtitles can be transmitted on cue without upsetting the sequence of pages. Nevertheless a control bit, C11 (Magazine Serial), is provided to allow the system to be used as if there were a single magazine of up to 800 pages.

6.1. Adaptive working

Adaptive working is the name given to a mode of transmission in which the time devoted to the transmissions of a page is adapted to the quantity of data conveyed. All blank rows, even those occurring between other rows of text, are omitted.

It has been estimated that use of adaptive working may reduce page access time by about 30%.

When working adaptively it is necessary for the transmission to provide a clearing instruction to the receiver when the contents of a page are changed so that old rows of text which coincide with blank rows of the new page shall be erased. This instruction is given when required by an Erase Page bit (C4) which is included in the Hamming protected section of the Page Header. Alternatively the first transmission may be made in full when a page has been newly changed.

It is moreover desirable, when working adaptively, that all pages should occasionally be transmitted in full to "sweep up" any accumulated errors which may be causing unwanted characters to be displayed on otherwise blank rows. Such erroneous characters would otherwise remain on display indefinitely. This would be particularly noticeable on receivers left unattended in public places.

7. Transmission sequence

As described in Section 5.1. each row of characters in the experimental CEEFAX system was fully addressed and the rows could therefore by sent in any order whatever. However, two transmission sequences seemed sensible. The data might be transmitted page-by-page (page sequential), each page being completed before transmission of the next; alternatively, the data might be sent row-by-row (row-sequential), where the transmission of a particular row of all pages is completed before transmission of the next row is begun.

For the experimental CEEFAX system row-sequential transmission was generally employed, it being thought initially that to start building up the selected page substantially at once would be more satisfactory to the viewer than causing him to wait some time for the page to appear.

With experience, however, it was felt that the page-by-page presentation is to be preferred and that the delay before a selected page is acquired is tolerable so long as it is not more than about 15 s. Page-sequential transmission was therefore adopted for Teletext. It should be noted that only as a result of using page-sequential transmission is it possible to place the page and time address only in the first row of each page as described in Section 5.1.

7.1. Page sequence

Pages are, in general, transmitted in order of increasing page number during each CEEFAX magazine transmission cycle, commencing with the lowest. Some pages, such as the Index page, can with advantage be transmitted several times during the Magazine cycle to provide faster access to them. Such page repeats fall out of the sequence of steadily increasing page numbers.

If CEEFAX receivers display the numbers of the pages currently being received, as many do, these out-of-sequence page numbers are momentarily flashed on the screen amongst the otherwise steadily advancing page numbers. Some people find this irritating. A control bit (C9) is provided in the page header to signal the presence of an out-of-sequence page number, so that its display may be suppressed should the receiver designer so choose.

7.2. Retransmission of page headers for clock

Transmission of change in the indication of the time-of-day clock displayed by CEEFAX receivers is currently carried by the next page-header to occur in the CEEFAX transmission cycle. As a result the transmitted time is delayed by a continually varying period of up to a quarter of a second. This effect is most noticeable in the inequality of length of the indicated seconds.

To improve the short-term accuracy of the clock a retransmission of the header of the current page could be made within 20 ms of each seconds change of the controlling clock. This inserted page header would not carry a clear bit and so would not erase data on other rows of the page already displayed on the screen.

After insertion of the extra header the remainder of the page would be completed in the normal way.

8. Display of alphanumerics

To permit maximum use of the data transmission capacity of the available television lines in the field blanking interval, the data is transmitted in a highly economical code sufficient only to identify each character transmitted. Similarly to save storage capacity in the receiver it is usual to store the identifying codes as received, not the characters themselves. To display the information in legible form a "character-generator" is required, to produce on the television screen the letters, numbers etc, corresponding to the stored codes.

8.1. The character generator

Although other methods of character generation

are in use for special purposes, economic necessity dictated that CEEFAX receivers should generate their characters by a simple and inexpensive method. The system was therefore designed on the assumption that a dot matrix technique would be used for character display.

In this technique selected dots, determined by the identifying code, are illuminated in a rectangular matrix of dot positions covering the display area of the character. Each dot position represents a bit cell in a read-only memory (ROM) and the character generator is a ROM containing the appropriate patterns of bits for every character which it may be desired to display.

If the display is on a television type raster, as with CEEFAX, dots for one row of the matrix are displayed on one television line, the identifying codes being changed character by character across the line. The matrix row address is then changed, and the other rows of the matrix are displayed in the same way, until the complete display of all characters in the row of text has been built up. Interlaced display on television involves repetition of the process in the alternate field.

Choice of the minimum satisfactory size of the dot-matrix to keep down the cost of the character generator ROM, reacts upon the number of characters per row, and directly upon the number of rows per page which can be displayed. In practice a dot matrix of 5 x 7 dots for capital letters, with tails of lower case letters accommodated by increasing the matrix height from 7 to 9 dots, results in a page of 960 characters (24 rows of 40 characters each) fitting conveniently into the television display area. The total capacity of the page represents a good compromise on store cost and usefulness. Fig. 4 shows typical CEEFAX dot-matrix characters.

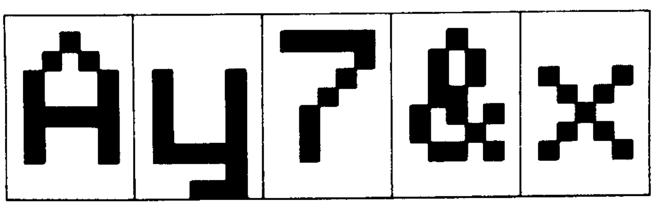


Fig. 4 - Typical CEEFAX dot matrix characters

Allowing one extra television field line for vertical separation between adjacent rows of characters therefore requires 10 television field lines, or 20 picture lines, for the display of each character row.

8.2. Character rounding

Double scanning of the dot matrix character generator once in the odd, and again in the even television field produces, somewhat coarsely structured characters of which each dot occupies two picture lines. Fig. 5 shows the effect. The diagonal strokes of these characters are made of square blocks positioned corner to corner, and apart from their coarsely stepped structure, have a mean width, and therefore mean brightness only $1/\sqrt{2}$ times

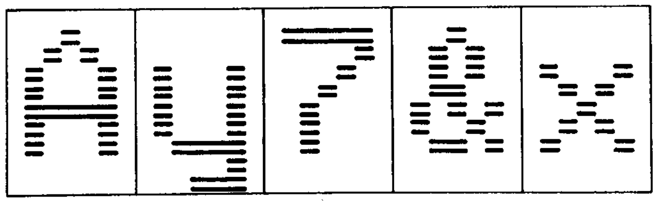


Fig. 5 - Effect of double scanning

that of the vertical and horizontal strokes.

A method of interpolation, known as character rounding, by means of which the character shapes can be improved as shown in Fig. 6 is well known for sequentially scanned displays of computer data on cathode ray screens. A modification of this technique for use with interlaced television displays was devised and patented in May 1973.[8] By its use the coarseness of the diagonal strokes is reduced and their brightness increased to be marginally greater than that of vertical and horizontal strokes. The additional cost of character rounding in a decoder using larger scale integrated circuits is extremely small.

8.3. Safe area

The limits of the area of a television picture which is suitable for the display of alphanumeric information have been specified by several authorities[9,10,11] and, in this report are referred to as the safe area. They were defined in width and height as percentage of the width and height of the transmitted picture, to ensure that captions would not be masked when displayed on a moderately overscanned receiver. The various sources define the limits as between 80% and 89% of width, and 76% and 88% of height.

8.4. Number of character rows per page

Using 10 television field lines per character row as

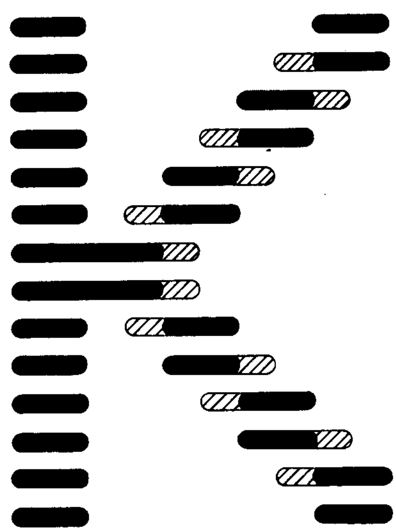


Fig. 6 - Effect of character rounding

described in Section 9.1. the range of recommended heights would accommodate 22 to 25 rows of characters. Since CEEFAX receivers yet to be built might be expected to use modern rectangular display tubes and provide fairly well stabilized vertical scans the tendency was to choose a number of rows per page near the top of the range. In the event 24 rows per page were chosen because this choice offered some advantage over 25 rows per page in simplicity of receiver logic design.

8.5. Number of characters per row

From the outset two forms of CEEFAX decoder were visualized one working with demodulated signals within the television receiver and applying its output directly to the CRT driving circuits, the second working in the aerial connection to the television receiver and providing its output at RF via remodulation. In the latter case the CEEFAX display would be subject to the band limitation, group delay and distortion of the receiver r.f., i.f., and detector circuits. Even with the simplest dot matrix characters, 5 dots wide and 1 dot spacing it was found that character legibility was impaired by such distortions if more than about 36 characters were displayed on one row. The effect was to broaden and reduce the brightness of vertical strokes of the characters compared to the width and brightness of horizontal strokes.

As a result of the above groundwork 32 characters per row were adopted for the pages of the original CEEFAX system. Discussions with members of BREMA later showed a declining interest in the 'add on box' approach to CEEFAX decoder design and an increasing commitment to decoders built into the television receiver for both economic and technical reasons. At this time also the CEEFAX editor was finding that 32 characters only per row were making the composition of attractive two-column pages such as the index page difficult. The opportunity was taken therefore to increase the number of characters per row to 40 when writing the Teletext specification.

8.6. Display control

A control character, read from the page store, controls the colour, or some other feature of all the characters which follow it until either it is superseded by another control character, or the row ends.

Since the television display cannot be halted whilst a control character is examined a character display area occurs on the screen for a control character as for any other. Control characters, with one exception to be dealt with later, are therefore transcoded by the receiver and applied to the character generator for display as spaces. A space therefore occurs in the display where any mode change, such as a change of colour, occurs. In text, control characters take the place of the normal spaces between words wherever colour changes are needed. Repetition of the control character currently being obeyed, in subsequent spaces, is permitted.

8.6.1. Colour control

The colours available are those obtained by on-off control of the receiver colour guns namely, red, green, blue, cyan, yellow, magenta and white. Black is used only for background, not for characters, since the display of black characters on a receiver not equipped for 'New Background' display (as discussed below) would result in disappearance of the text.

From the Teletext code table as shown in Table 1 it will be seen that there is a direct correspondence between bits, 1, 2 and 3 and use of the red, green and blue guns following the colour control characters, columns 0 and 1 rows 1 to 7. This direct correspondence between bits and guns simplifies the design of the CEEFAX decoder.

8.6.2. Display polarity and background colour

At the outset the display polarity of CEEFAX information was considered to be optional, white on black or black on white, at the user's choice, although it was realised that some television receivers may not be able to display larger areas of peak-white satisfactorily. White on black also appeared to be preferred by most users. White on black therefore came to be used more frequently than the inverse.

With the advent of coloured characters a difficulty arose in that a colour chosen say, for boldness, (e.g. yellow) by the CEEFAX editor working with a black background appeared quite insignificant when displayed against a white background. It therefore became necessary for the background colour on domestic displays to be the same as that on the editor's composing screen in order that his artistic effort should make sense.

In the specification for Teletext therefore black is considered to be the normal background colour, although an extension of the display capabilities has been obtained by designating one of the previously unused control characters as a 'new background' instruction, upon the receipt of which the background colour changes to the current character colour. The characters can then be displayed in any other of the available colours by transmission of the appropriate colour-control character.

8.6.3. Flashing display

To permit the CEEFAX editor to draw attention to information of special importance a flashing facility is provided in CEEFAX receivers, activated between control characters 0/8 (Flash) and 0/9 (Steady) inserted in the transmissions. In the 'Flash' mode the part of the display designated flashes on and off at about one flash per second under the control of an oscillator in the CEEFAX decoder.

8.6.4. Concealed display

To increase the usefulness of CEEFAX as a teaching aid a control character has been provided by which the tutor may instruct receivers to conceal parts of the display, such as the answers to questions, until the pupil presses a reveal key to check his own answers.

b7 b6 b5 →					0 0 0	0 0 1	0 1 0		0 1 1		1 0 0	1 0 1	1 1 0		1 1 1	
Bits b4	b3	b2	b1	Row / Col	0	1	2	2a	3	3a	4	5	6	6a	7	7a
0	0	0	0	0	NUL[1]	DLE[1]			0		@	P	—		p	
0	0	0	1	1	Alpha^{n} Red	Graphics Red	!		1		A	Q	a		q	
0	0	1	0	2	Alpha^{n} Green	Graphics Green	"		2		B	R	b		r	
0	0	1	1	3	Alpha^{n} Yellow	Graphics Yellow	£		3		C	S	c		s	
0	1	0	0	4	Alpha^{n} Blue	Graphics Blue	$		4		D	T	d		t	
0	1	0	1	5	Alpha^{n} Magenta	Graphics Magenta	%		5		E	U	e		u	
0	1	1	0	6	Alpha^{n} Cyan	Graphics Cyan	&		6		F	V	f		v	
0	1	1	1	7	Alpha^{n} White[2]	Graphics White	'		7		G	W	g		w	
1	0	0	0	8	Flash	Conceal Display	(		8		H	X	h		x	
1	0	0	1	9	Steady[2]	Contiguous[2] Graphics	)		9		I	Y	i		y	
1	0	1	0	10	End Box[2]	Separated Graphics	*		:		J	Z	j		z	
1	0	1	1	11	Start Box	ESC[1]	+		;		K	←	k		¼	
1	1	0	0	12	Normal[2] Height	Black[2] Background	,		<		L	½	l		‖	
1	1	0	1	13	Double Height	New Background	-		=		M	→	m		¾	
1	1	1	0	14	SO[1]	Hold Graphics	.		>		N	↑	n		÷	
1	1	1	1	15	SI[1]	Release[2] Graphics	/		?		O	#	o		■	

TABLE 1 - CEEFAX code table

[1] These control characters are reserved for compatibility with other data codes

[2] These control characters are presumed before each row begins

Codes may be referred to by their column and row e.g. 2/5 refers to %

Character rectangle

Black represents display colour
White represents background

Operation of the reveal key will normally be taken to reveal all the answers on a single CEEFAX page simultaneously, since to reveal single answers in sequence would complicate the receiver, and make the reveal facility inapplicable to diagrams occupying several CEEFAX rows.

8.6.5. Boxed display

All CEEFAX display so far considered in this report has been unconnected with the television programmes being simultaneously transmitted to the receiver. In devising the Teletext system considerable effort was spent in arranging that Teletext and Television could be used in conjunction. The technical possibility of using CEEFAX to subtitle television programmes, provide news flashes for viewers watching television, and perhaps provide supporting material for non-fiction programmes, was realized at an early stage.

For these applications simultaneous viewing of CEEFAX and television is necessary. The simple and obvious course of mixing the television and CEEFAX signals for application to the receiver colour guns is available to receiver designer but, predictably, the resulting CEEFAX display is often extremely difficult to read when superimposed on picture detail.

To permit clear, readable display of CEEFAX information together with television, control characters are provided to instruct the receiver to insert its CEEFAX displayed message in a 'box', without the picture, providing a uniform background against which it will be entirely legible.

The control characters define row by row the positions at which the box should start and end, and so the box can be made to blank out the smallest practicable area of the television picture.

The 'start box' and 'end box' characters are each transmitted twice in succession for each command in order to provide a measure of protection against spurious boxing of parts of the television picture due to CEEFAX transmission errors. It is intended that the box starts and ends between the positions of the two box control characters on the screen. This does not represent a causality problem, since characters are read out of the receiver page store in advance of their display time on the screen.

All characters intended for display on Newsflash and Subtitle pages are in boxed mode, and control bits C5 and C6 named Newsflash Indicator and Subtitle Indicator respectively in the page header, are provided to switch the Teletext receiver into picture display whenever a page of this kind is selected, so that the 'boxing' into picture can take place automatically. The distinction is made between Newsflash and Subtitle as they may be displayed or used differently.

The use of boxed characters on other pages not carrying newsflash or subtitle control bits is not excluded in the Teletext specification. Such use of the boxed mode would define a part of the page which could be set into the television picture under user control, alternatively the complete page could be displayed alone or superimposed on the picture.

8.6.6. Double-height

A pair of control characters is provided to permit double-height display of text. This facility may be used to emphasize certain words or, alternatively, may be used to make 'large print' for readers with poor eyesight. The double-height mode incidentally operates also upon graphics characters, but in that case little advantage is gained since the vertical resolution is halved and better results could be achieved in normal-height mode.

In double-height mode, character codes for a particular transmitted row number are taken by the receiver to apply to the next higher row number also, i.e. the characters are stretched downwards, to occupy the row for which they were transmitted and also the row below. Characters received for the lower row are ignored when the double-height mode control character appears in the upper row. The remainder of the lower row, not occupied by the lower halves of double-height characters, is displayed in the background colours in force for the various parts of the upper row.

8.6.7. Initial display-mode

To avoid the waste of space which would occur at the beginning of each row if all features of the display mode required to be set up by control characters, the Teletext specification lays down the assumed starting mode for every row. The starting mode was chosen to be the one most generally employed.

It is, alphanumerics, white characters on black background, revealed, steady, unboxed, normal height. If graphics mode is later selected by transmission of a control character Contiguous and released versions of graphics mode are also assumed.

9. Graphics

The desirability of providing some form of graphics display to enhance the attractiveness and use of CEEFAX as a domestic data system was realized from its inception. It was also clearly desirable that the graphics facility should contribute very little to the cost of the domestic CEEFAX receiver. Conventional computer line drawing techniques were first examined but were found to be too complex, so a dot matrix system was postulated. To keep receiver costs down the page store used for alphanumeric display had to serve also for graphics. The graphics display codes to be stored were therefore limited to seven bits and are some of the same codes already in use for alphanumerics. The alternative use of the same codes for both graphics and alphanumerics is controlled by a shift system comparable to the number – letter shift widely used on teletype. The shift characters are seen in the character code table

(Table 1) alphanumeric shift being initiated by control characters 0/1 to 0/7 and graphics shift by control characters 1/1 to 1/7.

Since a graphics character display matrix, unlike its alphanumeric counterpart, will be expected to be capable of displaying all possible combinations of the illuminateable dots it contains, a small matrix of 2 x 3 dots corresponding to each character code is appropriate. By dividing the display rectangle controlled by each code into two columns and three rows, Fig. 7(*a*) each of the six dots so defined can be directly controlled by one bit of the transmitted code as shown in Fig. 7(*b*). By adopting this direct correspondence between bits and dots, the need for a graphics character generator in the receiver is eliminated and the receiver cost is kept down.

Some approximations must usually be made in the design of the display circuitry in order to give a nearly regular matrix of graphics 'cells' within the limits of the number of scanning lines and the vertical resolution of the graphics display.

The complete CEEFAX page area of 40 x 24 characters gives a graphics resolution of 80 x 72 dots, or neglecting the page header 80 x 69 dots. This limited resolution has been found adequate in practice for the drawing of simple diagrams, graphs, histograms, logos and the like. It has also proved particularly successful for the creation of varied fonts of large text by the editorial staff, to make CEEFAX presentation more enjoyable to the viewer.

9.1. Contiguous and separated graphics

As described above the individual dot cells of the graphics matrix are contiguous and an area in which all dots are illuminated appears as a plain area of the chosen display colour. Provision is also made for a graphics mode, called up by transmission of a special control character, in which the dot cells are separated. By the use of the separated graphics mode large areas which would otherwise be plain may be displayed patterned by vertical and horizontal lines. Again some compromise must be made in the display as a

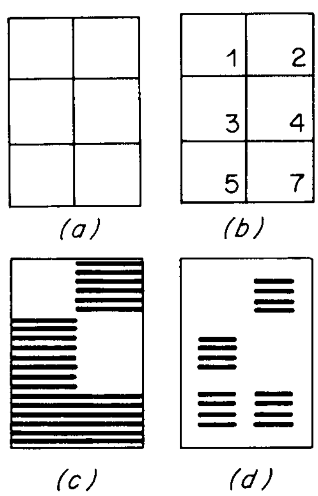


Fig. 7 - Graphics character matrix

perfectly regular matrix is difficult to achieve. Figs. 7(*c*) and 7(*d*) illustrate picture lines illuminated when displaying same code as contiguous and separated graphics respectively.

9.2. 'Blast-through' alphanumerics

To provide all possible combinations of illuminated dots in the 2 x 3 graphics dot matrix, requires only 64 different characters. In choosing these from the 96 display characters in the code table columns 4 and 5 containing the upper case alphabet were avoided.[12] This permits the upper case alphabet to be used in graphics mode without interposing a space for mode change. This facility is valuable for such purposes as writing place names on maps etc.

9.3. Hold graphics

The display of a space transcoded from a control character as mentioned in Section 9.7. prevents the abutment of two graphics characters of different colours on the same character row. This effect may be particularly unwelcome in displaying maps since it inserts a vertical stripe of the background colour, often representing a significant area of the country mapped, between the two regions distinguished by the colours.

To overcome this limitation at least in part, a 'Hold Graphics' control character has been provided. After the 'Hold Graphics' character has been received it and later control characters are themselves displayed not as spaces, but as repeats of a previous graphics character 'Hold Graphics' permits a limited range of abrupt changes in graphics boundaries between different colours. A 'Release Graphics' control character is available to cancel the effect of 'Hold Graphics'.

10. Control bits in page header

The effect of most of the control bits, which are included in the highly protected portion of the page header transmission, has in most cases been dealt with in the appropriate sections of the report. Table 2 shows where information about the action of each can be found.

Three controls bits remaining are C7 the 'suppress header' bit, C8 the 'update indicator' bit and C10 'inhibit display' bit. The suppress header bit is set to 1 when the page is better displayed without the characters of the page-header.

The update bit may be set to 1 when part or all of a page contains significantly new information. The updated page transmission may be incomplete, containing only updated rows. This control signal is intended to alert the viewer who has selected his favourite page, read it and is now watching television, to the fact that worthwhile new information has now appeared on his page. The method of alert is left to the receiver designer.

The inhibit display bit is set to 1 when the contents of a page cannot usefully be interpreted as a CEEFAX transmission. It can be used to inhibit the display of

TABLE 2

Cross reference for action of control bits

CONTROL BIT NUMBER	NAME	REPORT SECTION
(C1)	Magazine Address	4.1.
(C2)		
(C3)		
C4	Erase Page	6.1
C5	Newsflash Indicator	8.6.5
C6	Subtitle Indicator	8.6.5
C7	Suppress Header	10
C8	Update Indicator	10
C9	Out of Sequence Header	7.1
C10	Inhibit Display	10
C11	Magazine Serial	6
C12	Unallocated	
C13		
C14		

apparently meaningless pages of data which may then be used for other purposes.

11. Use of pages

11.1. Self changing pages

The ordinary Teletext page of 960 characters (40 x 24), equivalent to about 3 column inches in a newspaper, is quite suitable for concise treatment of factual information on many subjects. There are, however, some cases in which more space is required, the publication of long lists such as football results for example. To provide the additional space when needed without requiring the viewer to 'dial up' a number of pages, self changing pages are used. A group of self changing pages is transmitted in rotation using the same page number in the page header. The interval for which each of these 'sub-pages' is displayed is controlled by the CEEFAX editor to allow reasonable time for the average viewer to read the contents. Inevitably, as with other, recorded, information services, users often acquire the information part way through the cycle and have to wait for the beginning. This limitation may be accepted by the user.

11.2. Time coded pages

To increase the size of the magazine beyond that which could be transmitted with reasonable access time using a simple unbranched transmission cycle, CEEFAX provides an additional 'Time' code. This code was intended to give the hours and minutes of the transmission time in BCD, to allow any page to be selected during one particular minute of the day and held for subsequent viewing. This would allow a very wide range of subjects to be dealt with by changing some pages minute-by-minute throughout the day.

During the two-year experimental period little use was made of this facility, as unreasonable editorial effort would have been required to compile such a mass of information for the then limited audience.

Later it was realised that a more flexible use could be made of the time code by allowing it to take a fuller range of numbers, and to allow the code to differ from the actual transmission time, these changes, which were included in the Teletext specification, allow the time code to be used as an address extension. For example, the different sub-pages in a self changing cycle could each carry a Time Code to allow a known sub-page to be automatically selected and held. If a particular page were transmitted so infrequently that it is necessary to know when the decoder should be switched on it is still appropriate to associate the Time Code with the transmission time.

The use of Time Codes with extended cycles of sub-pages will become increasingly useful when multiple page stores, using, for example, magnetic tape cassettes, become widely available. It would then be possible to select and store many related pages in correct sequence.

12. Other display possibilities

In the early stages of CEEFAX development considerable attention was devoted to the idea that several levels of receiver instrumentation might arise. In particular that if a receiver making use of every aspect of the transmission were to prove moderately expensive, some cheaper form of receiver making use of only some of the facilities might to viable to provide 'Poor man's CEEFAX'. Such a receiver was conceived as having, perhaps, a single row display, the letters of which might move across the screen in the manner of the well known news display in Times Square, New York.

As large scale integrated circuit equipment for CEEFAX decoders and displays was discussed with intending manufacturers it became clear that there was no intention of marketing anything other than 'full service' equipment which would utilize every known feature of the transmission. It was also clear that the 'full service' equipment would in production, eventually become relatively cheap. The possibility of undercutting the price of 'full service' receiving equipment by making a poorer version of interest to a limited section of the public was at this stage seen to be very remote.

There remains however the possibility that, should some display other than the generally used one be desirable, 'special displays' (such as a tactile Braille output) can always be provided, but probably at a greater rather than a lesser cost. Should such a display method warrant,

also, a special data stream, such additional transmission could readily be provided within the existing framework of Teletext by invoking the 'Inhibit Teletext' control bit.

13. Conclusions

The development effort which has been put into almost every aspect of domestic data broadcasting since 1972 has yielded a new public service, the technical parameters of which are well suited to its future development over an extended period.

Great care has been taken to avoid, on the one hand, under extending present day technology which would lead to an impoverished service rapidly becoming obsolescent, and on the other, over extension of technology leading to difficult, expensive and unsatisfactory results in the early years. Operational experience so far shows that the choices have been well made.

14. References

1. 1976 Broadcast Teletext Specification, BBC, IBA, BREMA. ISBN 0 563 17261 4.
2. LE COUTEUR, G.M. 1974. CEEFAX: interference with television from data signals transmitted in the field-blanking period. BBC Research Department Report No. 1974/10.
3. TANTON, N.E. 1975. CEEFAX: tests on three possible choices of secondary code. BBC Research Department Report No. 1975/18.
4. HECHT, M. *and* GUIDA, A. 1969. Delay Modulation Proc. IEEE, July 1969, pp 1314-1316.
5. STEBBINGS, D.W. 1975. CEEFAX: UHF field trials. BBC Research Department Report No. 1975/12.
6. GILCHRIST, N.H.C. 1976. CEEFAX: an investigation of interference from Teletext data signals into the sound circuits of domestic television receivers. BBC Research Department Report No. 1976/17.
7. HAMMING, R.W. 1950. Error detecting and error correcting codes. BSTJ. **27**, 2, pp 147-160.
8. ROBERTS, A. 1973. Patent Specification No. 1416226. Generation of dot matrix characters on a television display.
9. BS 2962. 1958. Picture areas of motion picture films for television.
10. BS 2948. 1965. Slides and opaques for television.
11. SMPTE. 1968. RP8-1968. Safe action and safe title areas for TV transmission.
12. ROBERTS, A. 1974. Patent Application No. 30817. Improvements relating to data display systems.

Appendix

A Comparison Between Three Methods of Transmission of Eight Message Bits in a Gaussian Channel

Let bit error-rate by 'p'. Hence the probability that a particular bit is correct is $(1 - p) = q$.

1. Unprotected transmission of the eight-bit message

The probability of correct transmission of all eight message bits is q^8. Hence the probability of false transmission is $1 - q^8$.

2. Double transmission of the eight-bit message with bit-by-bit comparison test for agreement at the receiver

Probability of correct transmission is q^{16}.

Probability of false transmission, (i.e. undetectable error), is

$16p^2q^{14} + 112p^4q^{12}$ (neglecting higher-order terms).

Probability of rejecting a wrong message is therefore

$$1 - (q^{16} + 16p^2q^{14} + 112p^4q^{12})$$

3. Transmission by incorporating the eight-bit message as two four-bit words in two eight-bit Hamming Code groups

Probability of various numbers of bits in error in an eight-bit group is given by the binomial distribution

$$q^8 + 8pq^7 + 28p^2q^6 + 56p^3q^5 + 70p^4q^4 + 56p^5q^3 + \\ + 28p^6q^2 + 8p^7q + p^8$$

(Thus q^8 is the probability of all bits being correct, $8pq^7$ is the probability of one bit-error, $28p^2q^6$ two bit-errors, $56p^3q^5$ three bit-errors etc.)

Because a single bit-error can be corrected, the probability of a single, eight-bit single-error-correcting Hamming Code group being received correctly is

$$q^8 + 8pq^7$$

(i.e. probability of 8 bits TRUE + probability of 7 bits TRUE.) Hence the probability of two Hamming Code groups being received correctly is

$$(q^8 + 8pq^7)^2$$

The probability of a double-error occurring in a single code group is

$$28p^2q^6.$$

Hence the probability of a double-error being detected in one or both of two code groups is

$$\underbrace{(28p^2q^6)^2}_{\text{Probability of a simultaneous double-error in both groups}} + \underbrace{2(28p^2q^6)(1 - 28p^2q^6)}_{\text{Probability of a double-error in one group only}}$$

Hence the probability of two eight-bit Hamming Code groups giving an undetectably false transmission is

$$1 - [(q^8 + 8pq^7)^2 + (28p^2q^6) + 2(28p^2q^6)(1 - 28p^2q^6)]$$

These results are plotted for bit error-rates from 10^{-1} to 10^{-3} (Fig. 3).

HR/VY